14.—The Archean succession to the west of Lake Lefroy

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Abstract

This paper summarises and correlates work carried out on the early Precambrian Kalgoorlie System (c. 2700 m.y. metamorphic age), in the area to the west of Lake Lefroy, by the author and by five students whose work he supervised. It includes a map of the entire area, a statement of the stratigraphy derived, and general accounts of the physiography and geology, including notes on the overall structural pattern and possible correlations with better known sequences to the north and south, at Kalgoorlie, Coolgardie and Norseman. While the synthesis is based on the results obtained by all six geologists, the conclusions drawn are entirely the responsibility of the author named. It is intended to publish further accounts giving the results of the investigations of certain sub-areas in more detail.

The stratigraphy deduced involves seven sedimentary units, together with a number of ophiolite belts: of the seven sedimentary units, three are exposed to the east and four to the west of a dislocation, the Yilmia dislocation, which appears to have a significant sinistral transcurrent displacement. The three eastern units are believed to be equivalent to the lower three of the four western units. Any stratigraphic resolution of this area must involve the acceptance of significant lateral thinning and thickening—that is, an essentially lensed sequence, whether by tectonic or sedimentological agencies or a combination of both. Another dislocation separates the eastern three units from the Kambalda ophiolites; no detailed stratigraphy is given for these, which are much better known by the geologists of the Western Mining Corporation. However, the major structure, a synclinorium, deduced from unequivocal facing indications, seems to require that the nickel sulphide bearing ophiolites of Kambalda are, broadly speaking, stratigraphically equivalent to similar nickel sulphide bearing ophiolites, associated with only thin, dominantly pelitic metasediment intercalations, that extend from Widgiemooltha southwards through Higginsville.

Introduction

Early in 1964 an area to the west of Lake Lefroy, in which rocks of the early Precambrian Kalgoorlie System are exposed, was selected as the subject of a detailed field and laboratory study, to be carried out by a group of workers over a period of several years. This particular area was chosen on account of excellent lake-shore exposures of fresh metamorphic and igneous rocks, and because of the peculiar problem posed by the porphyroid conglomerates: and it was also thought that such a programme might lead to the establishment of the geological succession from Red Hill (Kambalda), a point on the southerly continuation of the Golden Mile "greenstone" (ophiolite) belt, southwards to Widgiemooltha—from which point an extension of mapping could later be carried out southwards to Norseman, thus connecting up the two gold mining areas about which much is known of the geology and stratigraphy (Bekker, 1963: Woodall, 1965).

The objects of these investigations were:

a. establishment of a stratigraphic sequence.

b. study of primary structures and texture of the sediments, and the palaeogeography.

c. study of the regional metamorphism: with particular reference to testing the validity of the *Green Schist Facies* as defined by Turner and Verhoogen (1960).

d. Investigation of the nature and origin of the "porphyroid conglomerates"—rocks which have the character of albite porphyries, but contain traces of conglomeratic structure, and show atypical cal microtextures.

c. investigation of the complex meta-igneous basic and ultrabasic rock belts: commonly called "greenstone" belts, but perhaps, better referred to as "ophiolites", special attention being paid to igneous associations.

f. investigation of the post-metamorphic, east-west trending, dolerite dykes on a regional scale, with particular reference to the problem of the alkalic basalt and tholeiitic basalt associations.

g. to deduce the regional tectonic structure.

The first stage of this programme, mapping to Widgiemooltha, was completed at the end of 1966. The six geologists concerned, J. C. Braybrooke, J. J. G. Doepel, G. J. H. McCall, D. D. Middleton, P. C. Muhling and W. R. O'Beirne, have contributed. The author has supervised the entire project; W. R. O'Beirne, while engaged on a thesis study for the Ph.D. Degree, has concentrated on the problem of porphyroid metasomatism with him; the remaining four geologists have been engaged in thesis studies for the Degree of B.Sc. with honours (approximately equivalent to the Masters Degree in America) and have mapped individual sub-areas in detail.

The area mapped is shown in Figure 1, and in detail in Figures 2, 3 and 4, which also show the component sub-areas covered in the field by individual geologists.

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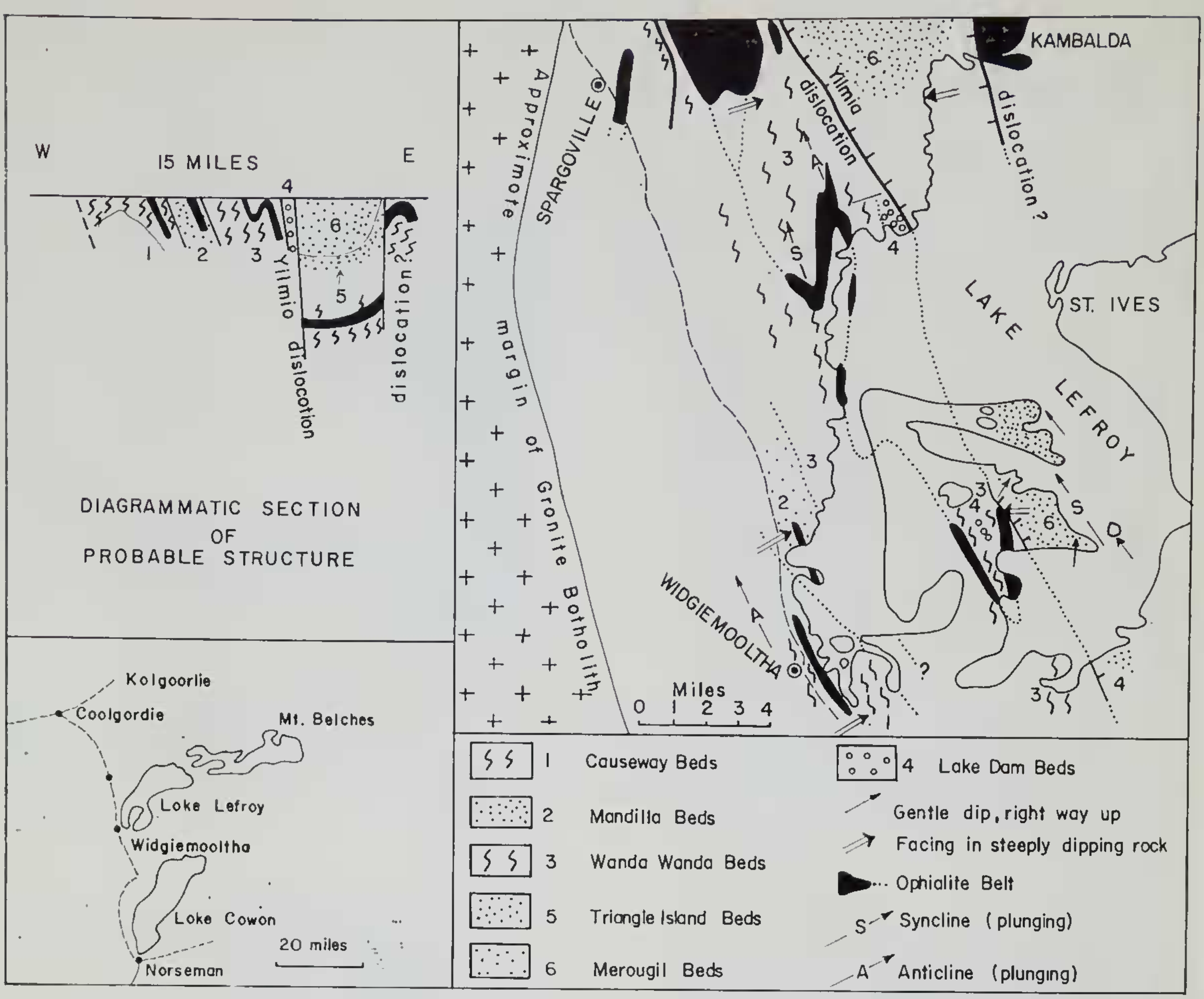

Figure 1.—(a) Location diagram. (b) Stratigraphic and structural relationships of the various rock units of the area. (c) Diagrammatic section across the area.

The area lies between the western shore of Lake Lefroy and the Coolgardie-Esperance Highway; extending from the latitude of Spargoville and Red Hill in the north to a point one mile south of Widgiemooltha. The "Lefroy Peninsula"* is also included. The lake area is solid ground for most of the year, Lake Lefroy being a saltpan which is only seasonally covered by a thin sheet of salty water, which moves erratically from side to side with change of wind.

The method of mapping used was:

a. Detailed coverage of sub-areas a mile or two in diameter, using air-photographs (40 chains to the inch sets of the Lands and Surveys Department and flights of low level photos taken for the Western Mining Corporation before the World War, and available either on the scale of 600 feet to the inch or on 1,200 feet to the inch).

Sub-areas mapped in this way were:

Merougil Creek—J.C.B., D.D.M. (3 weeks)

Yilmia Hill—J.J.G.D. (3½ weeks)

Bayley's Workings (Pilbailey Hill, southern part)—P.C.M. (5 weeks)

Widgiemooltha—G.J.H.M., W.R.O'B. (3 weeks)

Lefroy Peninsula—G.J.H.McC. (1½ weeks)

Emu Well—G.J.H. McC (4 weeks)

b. The remainder of the area, much of which is inland terrain of sparse poor-quality exposure, was mapped by G. J. H. McCall, mainly by traverses along tracks and through the bush. The coastal area near Lake Dam, the northern part of Pilbailey Hill and the Wanda Wanda Creek area were mapped in some detail.

* Informal name, coined for convenience by the writer —G. J. H. McCALL.

This text is prepared by the author (1) from his own notes and maps; (2) from theses prepared by four of his associates (Braybrooke and Middleton, 1964; Doepel, 1965; Muhling, 1965).

Physiography

The area lies in Jutson's "salinaland" (1934, p. 32) and there are three distinct erosion levels represented.

Residual Hill Features—standing out as rocky ridges, which display bouldery outcrop and stand above the general level of the surrounding plain. These, the "inselbergs" of Jutson, are mainly formed of resistant meta-igneous basic and ultrabasic rocks ("greenstones").

Lateritised Plain—the "old plateau" surface.

Lake Basins—scooped out by erosion subsequent to the formation of the lateritised plain and bordered on the west by fresh rock outcrop in the form of low cliffs; their eastern shores are formed of kopai (gypsum) dunes which obscure the bedrock. The origin of these lake basins is debatable but it is quite obvious, viewing them from the air, that they represent a former drainage system now degraded to a branching system of discontinuous lakes.

Residual Hills in this area are those of Red Hill, Yilmia, Pilbailey Hill, the hill near the mouth of Wanda Wanda Creek and the hill of serpentinite which forms the highest feature of the Lefroy Peninsula. The lateritised surface, which forms the inland country elsewhere, does not seem to be a flat bevel, its level varying slightly up and down. It produces low lying areas of extremely poor exposure. The laterite is superimposed on a mottled zone which in turn passes down to kaolinised Precambrian rocks. The kaolinised sediments commonly show "Liesegang Ring" structures.

Rainfall is low (<10 inches per year) and temperatures range from $>100^{\circ}$F during the long summer to $<40^{\circ}$F during the cold, bleak, dry winter. The rain comes mainly in storms which sweep inland from the north-west coast at the end of cyclonic depression activity up there, during the summer months.

Surface coverings of siliceous hardpan, kunkar, surface limestone, magnesite and opal are common.

The vegetation is mainly of mulga, acacia, eucalypt, sandalwood and kurrajong on the metasediments; blue bush, salt bush and salmon gums on the laterite areas; and thicker growth of eucalypt and acacia on the belts of basic meta-igneous rocks ("greenstones"). The area is characterised by a remarkable lack of grass, stony earth surfaces intervening between scattered clumps of bushes and trees.

General account of the geology

Stratigraphy. The Kalgoorlie area has long been known to geologists on account of gold mineralisation at Kalgoorlie (in the Golden Mile) and Coolgardie, in the north, and Norseman in the south. This area lies between these mining fields and displays a wealth of metamorphosed sedimentary rocks. Early geologists tended to discount the presence of such metasediments, regarding the "greenstones" correctly as metabasic igneous rocks and much of the "whitestones" incorrectly as sheared porphyries or porphyrites. Some of the maps of fifty years covering part of the Lake Lefroy area show no metasediments at all. The extent of the metasediments in this particular area is correctly shown by Sofoulis and Bock (1962) and Sofoulis (1965), geologists who have carried out a regional survey, though without embarking on any differentiation of the metasediments as attempted here. The general geology of the belt of ancient rocks situated between immense bodies of almost equally ancient granite is well summarised by Prider (1961). The belt consists of abundant metasediments of geosynclinal origin (in the primary sense of Aubouin, 1966), locally isoclinally folded, displaying steep dips, and rather irregularly metamorphosed, though in general displaying *green-schist facies* assemblages. The regional sequence of events may be summarised:—geosynclinal sedimentation; ophiolite intrusion and extrusion; folding and metamorphism; granite* and albite-quartz porphyry* invasion (accompanied by porphyroid metasomatism of rudites?), late basic dyke intrusion on east-west fractures during a post-metamorphic period of tension. Some acid volcanics are present—but to what extent they are represented is debatable. The metamorphism has been dated as about 2,700 m.y. ago, the granite intrusion about 2,600 m.y. and the late dyke phase 2,420 m.y. ago (rubidium-strontium method, unpublished thesis, Turek, A., 1966).

It is now apparent from field and age-dating evidence that the granites bordering the belt represent later invasions of the ancient metamorphic rocks not a primitive Archaean basement beneath the sediments. Granite boulders in the conglomerates do, however, indicate a previous granite intrusion or granitisation episode and presumably a previous orogenic cycle.

The only later formations represented are the Plantagenet (Eocene) marine sediments, forming a very thin and sporadic sedimentary cover, and composed mainly of spongolite.

The area represents a continuation southwards of the sequence between Kalgoorlie and Coolgardie (Fig. 1), for which a stratigraphic sequence has long been accepted (covering the eastern half of the section):

* Much of the porphyries and at least some of the granite rocks experienced at least the last stages of tectonic deformation, associated with the orogeny; many of the porphyry bodies appear to be pre-orogenic.

Kurrawang Conglomerates

locally present

[Yindarlgooda (White Flag) Beds]

Black Flag Beds

Kalgoorlie Greenstones:
- Paringa Basalt*
- Golden Mile Dolerite*
- Williamstown Dolerite*
- Kapai Slate*
- Hannans Lake Serpentinite*
- (Woodall, 1965)

The names marked with an asterisk are satisfactory for a mining area stratigraphy of extreme economic importance but local significance. It is, however, questionable whether on a regional scale it is not preferable to name the internal subdivisions of the metabasites and ultrabasic rocks of the "greenstone" (ophiolite) beds informally. The belts change character rapidly along the strike, and such a stratigraphy is likely to have no extension outside the Golden Mile for which it was very rightly erected. They include ultrabasic rocks which are certainly intrusive, and basic sills; these intrusions may transgress, change character, or disappear along the strike, and are obviously better named informally in the present work, only individual "greenstone" (ophiolite) belts being given a name. It is evident as a result of recent work extending into the lower part of the sequence that some sequences predominantly composed of pillowed metabasalts will have to be given formal status as "Beds", but it is still maintained that attempts to extend the complex internal stratigraphy of the ophiolite belts for any distance along the strike cannot lead to anything but confusion. The older names given to the various stratigraphic units in the Kalgoorlie area are not extended to this area, though in Table 1, the probable correlatives and the general relationship of the Lefroy Succession to the Kalgoorlie Succession are shown.

Glikson, (1968) has produced a stratigraphic sequence for the rocks of the Kalgoorlie System outcropping in the Mungari-Kurrawang area, to the north of the area considered here, and to the west of the Kalgoorlie area. His sequence from Coolgardie to Kurrawang is:

Sedimentary units	*Igneous units*
Kurrawang Beds	
Black Flag Metasediments	
	—(Red Lake Ophiolites)
Brown Lake Metasediments	
	—(Mt Robinson Ophiolites)
Gunga Meta-argillites	
	—(Coolgardie Ophiolites)

The probable correlation between the rocks of the Lefroy area and this sequence is also given in Table 1.

As is seen from a study of Table 1, and figures 2, 3, 4 and 5 (together with the accompanying sectional diagrams), the stratigraphic sequence has been divided into seven units, four of which are exposed to the west of the Yilmia Dislocation and three to the east of the dislocation. It is believed that the three units to the east of the dislocation are equivalent to units 2 and the lower part of unit 3 to the west of the dislocation, the sequence facing in opposing directions on either side of the dislocation, the structure being a broken synclinorium and the dislocation being a fault with considerable sinistral transcurrent component, throwing down to the east

The stratigraphy given here represents a revision of the sequence given in a previous summary (McCall *et al.* 1967), before the likely nature of the Yilmia Dislocation was fully understood. It had been customary amongst geologists working in this area to regard the Kurrawang Conglomerates (Glikson 1968) as equivelent to the conglomerates of the Merougil Beds further south, and many mining company maps show them in virtual strike continuity. However, more recent detailed maps produced by mining company geologists suggest that such a correlation is untenable. The Abattoir Line, a complex ophiolite belt including sills and serpentinite, trends north-east to south-west (Fig. 5) and continues southwards to join up with the Cave Rocks Ophiolite Belt, which appears to be truncated by the Yilmia Dislocation to the south of Cave Rocks (Fig. 2). The Abattoir Line Ophiolite and the enclosing dominantly pelitic metasediments separate the Kurrawang Beds from the Merougil Beds. It is clear that the Merougil Beds form a very thickened sequence, part of the west facing limb of the southern continuation of the Kurrawang Syncline, but are much lower in the sequence than the Kurrawang Beds, being separated from them by the Abattoir Line Ophiolite Belt and the enclosing metasediments. This interpretation allows correlation of the Merougil Beds with the rather thinner sequence of conglomerate beds of strikingly similar character on the western limb of the syncline, the Mandilla Beds, outcropping on the shore of Lake Lefroy, north of Widgiemooltha: and the Wanda Wanda Beds to be equated with the Cave Rocks Beds, though, clearly, the equivalent sequence to the Wanda Wanda Beds and their equivalents to the north, the Black Flag, Brown Lake and Gunga Beds of Glikson (1968), are significantly thinned on the eastern limb. The Yilmia Ophiolite Belt thus becomes stratigraphically equivalent to the Abattoir Line Ophiolite Belt. The Merougil Beds wedge out northwards against the eastern of the two dislocations, to the west of the Kambalda Ophiolite Belt[1].

The stratigraphy given is based on abundant facing evidence—pillow facings, cross-bedding, graded bedding, soft rock deformation structures and internal differentiation patterns in layered sills. The beds are for the most part

[1] This dislocation, evidence for the existence of which is given by Braybrooke and Middleton, 1964, may well continue northwards to join up with the Boulder Fault, which separates the Mt Hunt Ophiolites, presumed to be stratigraphically equivalent to them, from the Kalgoorlie-Kambalda Ophiolites. The sense of the displacement on this fault is not fully established, but the downthrow appears to be towards the west.

TABLE 1

Table 1.—Probable correlation between the rocks of the Lefroy area, the Kalgoorlie Sequence and the Mungari-Kurrawang Sequence.

				CORRELATION WITH THE KALGOORLIE SEQUENCE Kurrawang Conglomerates (not represented in this area)	CORRELATION WITH THE MUNGARI KURRAWANG SEQUENCE (Glikson, 1968)	OTHER LIKELY CORRELATIONS
7. CAVE ROCKS BEDS	c. 200′ only limited outcrop	Metapelites† Metasandstones	CAVE ROCKS OPHIOLITE BELT	ABBATOIR LINE OPHIOLITE BELT AND ENCLOSING DOMINANTLY PELITIC SEDTS	RED LAKE OPHIOLITES BLACK FLAG BEDS	YILMIA MAIN OPHIOLITE BELT WANDA WANDA BEDS
6. MEROUGIL BEDS	16,000′	Metasandstones* Metaconglomerates* (polymictic) Metasiltstones		cut out by dislocation ?	Not represented ? Stratigraphic position between Gunga Meta-argillites and Coolgardie Ophiolites	MANDILLA BEDS
Possible gap or overlap						
5. TRIANGLE ISLAND BEDS	2,500′	Metasandstones* Metaconglomerates* (polymictic) Metasiltstones		cut out by dislocation	Not represented ? Stratigraphic position between Gunga Meta-argillites and Coolgardie Ophiolites	MANDILLA BEDS
YILMIA DISLOCATION						
4. LAKE DAM BEDS	300′	Sandstones* (undeformed clastic texture) Metasandstones* Chert or quartz fragment breccias* Metasiltstones				
3. WANDA WANDA BEDS	7,500′	Metasiltstones Metapelites† Metasandstones* Metaconglomerates* (polymictic) (quartz grits and actinolitic metasediments)	YILMIA MAIN OPHIOLITE BELT YILMIA WESTERN OPHIOLITE BELT	BLACK FLAG BEDS	BLACK FLAG BEDS BROWN LAKE BEDS GUNGA META-ARGILLITES RED LAKE OPHIOLITES MT. ROBINSON OPHIOLITES	CAVE ROCKS BEDS
2. MANDILLA BEDS	5,000′	Metasandstones* Metaconglomerates* (polymictic) Metasiltstones (actinolitic metasediments)	VESICULAR OPHIOLITE BELT			MEROUGIL AND TRIANGLE ISLAND BEDS
1. CAUSEWAY BEDS	7,500′	Metapelites† Metasiltstones Metasandstones* Metaconglomerates* (polymictic)	TOWN DAM OPHIOLITE BELT‡ (SPARGOVILLE OPHIOLITE BELT)		COOLGARDIE OPHIOLITES ? (near top of succession) and associated metasediments	KAMBALDA OPHIOLITES ? WOOLGANYER GROUP ? OF NORSEMAN (Bekker, 1963)
Bottom of sequence so far Mapped		Abundant actinolitic, tremolitic and hornblendic metasediments				

* Rocks of *metagreywacke* character or metaconglomerates with greywacke matrix.

† The term *metapelite* denotes metasediments finer than metasiltstones—strictly speaking "fine metapelites" (McCall & Dunbar, 1967): Glikson (1968) refers to these as "meta-argillites", but there are objections to this term.

‡ The Spargoville Ophiolite Belt is stratigraphically below the level of the lowest members of the Causeway Beds mapped at Widgiemooltha. It is believed to be in continuity with the Widgiemooltha Ophiolite Belt, just west of the township. The stratigraphy is only intelligible if it is accepted that there is a very drastic lateral thinning out northwards from Widgiemooltha, of tectonic or sedimentational origin (or both). The Causeway and Mandilla Beds thin out to the north: shearing increases and coarse clastic sediments become less evident. Similarly the equivalent formation to the Wanda Wanda Beds, containing the Abattoir Line-Cave Rocks Ophiolite Belt east of the Yilmia Dislocation appear to be attenuated.

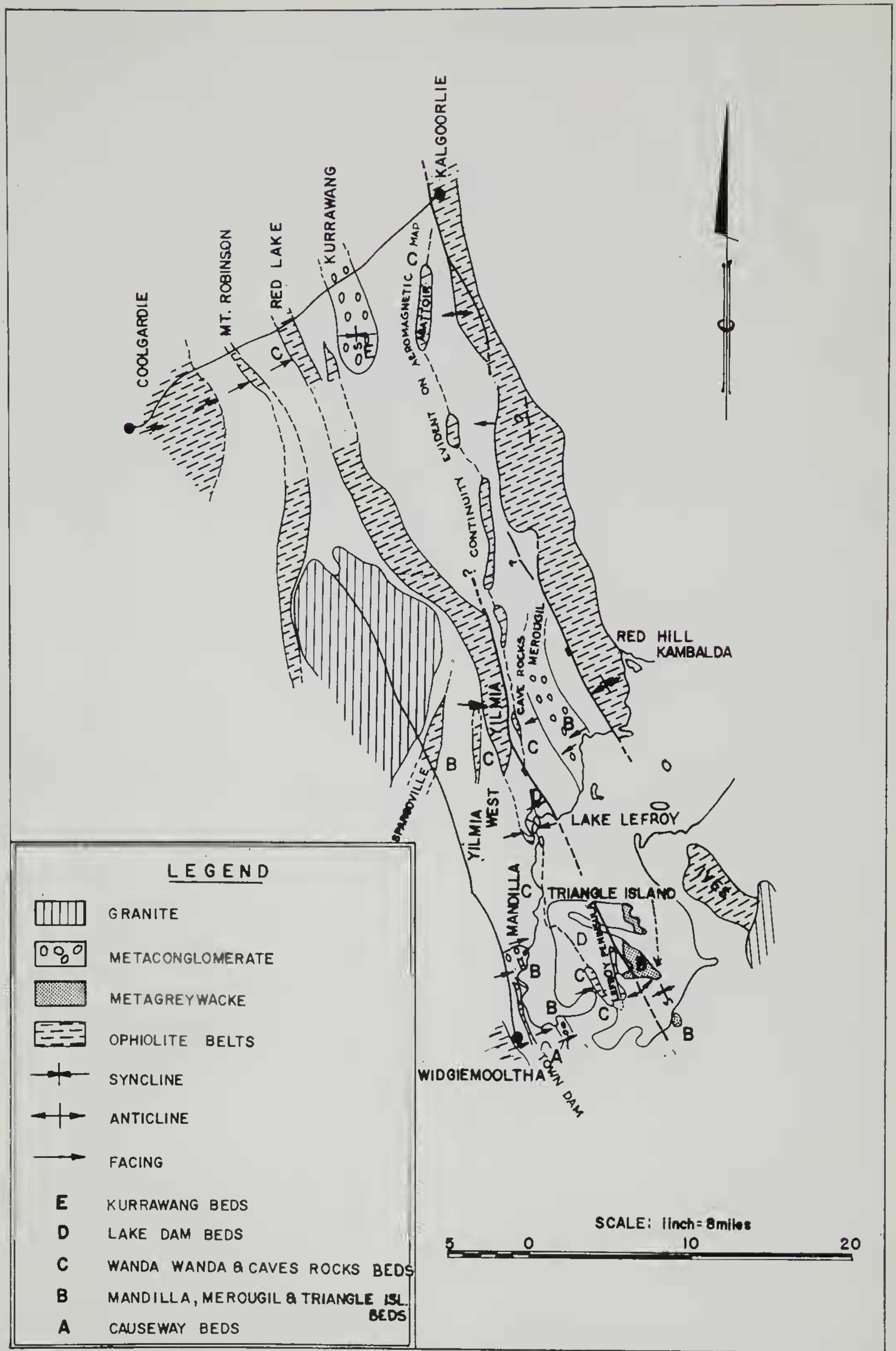

Figure 5.—Line diagram showing the possible correlation between the succession and structure of the area with with the formations situated to the north.

vertically disposed, but on the Lefroy Peninsula the keel of the gently north-plunging syncline is exposed in the outcrops of the Triangle Island Beds, which are taken to represent *either* their lateral equivalents or the lower part of that sequence, not exposed in the main outcrop near Merougil Creek because of truncation by the eastern of the two dislocations. The later explanation is preferred, and the stratigraphic table (Table 1) is drawn up in accordance with that preference.

The correlatives of the Lake Dam Beds, in which undeformed greywackes and sedimentary breccias composed of chert-like fragments are well developed, might well be found between the Abattoir Line Ophiolite and the base of the Kurrawang Conglomerates, in the eastern limb of the Kurrawang Syncline. It is noteworthy that the ophiolites of the Kambalda Belt are invaded by a number of small granite bodies with a marginal and outlying development of a porphyry phase. The conclusion was drawn by O'Beirne (1968) that these rocks suffered at least the terminal stages of deformation and metamorphism. Similar rocks are a feature of the ophiolites of the belt running through to the west of Widgiemooltha, especially near Dordie Rocks, and one may well enquire whether these intrusions do not have some indirect relationship to the concentration of nickeliferous sulphides—even though these are reportedly "post-ore?". Probably, there is evidence in the Kambalda Mines which would resolve this question.

The conclusion is drawn that the Kambalda Ophiolites and those to the west of Widgiemooltha are, like those at Coolgardie, near the base of the succession so far mapped. There is certainly some validity in the concept of an "ophiolite group", but the term is perhaps misleading for ophiolites occur at many levels in the stratigraphic succession. Preliminary mapping between Widgiemooltha and Norseman suggests that the ophiolites of the belt which develops in the Causeway Beds just above the Town Dam Ophiolite Belt immediately south of the area may be equivalent to the Desirable Pillow Lavas of the Norseman succession (Bekker, 1963), and it appears that all the thick Norseman sequence beneath this level is stratigraphically lower than the entire sequence given here.

Structure. It is apparent from the sections that the overall structure is a large scale synclinorium with the median zone complicated by two dislocations. Two complementary anticlinal structures border the synclinorium, one to the west of Widgiemooltha and the other passing through Kambalda. The metamorphic rocks have a north-north-westerly regional trend, and wedge out against a north-south trending granite contact, which indicates the intrusive nature of the granite, to the west of the area mapped.

No evidence of the interference fold pattern recognised by Horwitz and Sofoulis (1965) has yet been found within the limited area mapped. Lineation plunges are mostly north-north-westwards and gently inclined, though some moderately steep plunges are recorded, as well as some gentle to moderately steep southward plunges. In one outcrop near Widgiemooltha steep and westwards plunging small scale folds of isoclinal style were noted only inches away from a set of gently north-north-westward plunging lineations.

Some distance to the north of Widgiemooltha steep westerly plunges were again recognised, in crenulations within a jasper bar. These aberrant lineations certainly testify to cross folding in the area, of some sort, but there seems to be no evidence that it is not of simultaneous type, and the fold geometry does not seem to exactly match that deduced by Horwitz and Sofoulis (1965).

The thick sequence of the Merougil Beds has a homoclinal structure, there being no significant internal flexures of small scale in the thousands of feet thickness exposed. The thickness of this sequence could be overestimated for the upper and major part of the thickness given in Table I is only poorly exposed, and some of it could be equivalent to the lower part of the Wanda Wanda Beds.

In general, it seems that complex flexures, mainly isoclinal, though undoubtedly present in the sequence studied, are mostly localised within incompetent pelitic metasediment sequences and are second and third order flexures superimposed on a system of first order major flexures which can only be detected by facing measurements, and have wave lengths of tens of miles. Thus, while it has been suggested that facing indications are valueless in a sequence displaying such complex flexures which produce repetitions of the stratigraphic sequence, the mapping has shown that there is a consistent facing direction maintained over many miles across the strike, and that the general pattern of the first order folds does emerge from recording these facing indications, in spite of localised reversals which can be related to second and third order flexures.

No evidence has been found for major unconformity within the sequence, though there are minor discontinuities. While it is, admittedly, difficult to detect unconformities in such tectonically smoothed-out sequences and to be sure of the significance of those that are recognised, it seems to be a fact of critical significance that the sedimentary rocks of the Causeway Beds include polymictic conglomerate members that are lithologically very similar to the conglomerates of the uppermost beds of all, the Kurrawang Conglomerates. Though the amphibole content is rather higher in these lower conglomerates, and metapelites predominate over psammites and rudites in the sequence as a whole, the conglomeratic members contain porphyry, laminated metasediments, granites, quartzite and chert phenoclasts in that order of abundance, set in a highly altered greywacke matrix—a very similar phenoclast lithology to that of the Kurrawang Beds. The Kurrawang Conglomerates cannot be taken as indicative of very special conditions pertaining at the end of the deposition in the geosyncline, only of a general tendency for rudites to predominate in place of pelites: and it does not seem acceptable to give them a molasse connotation.

The immense thickness of sediments and igneous rocks inferred (McCall *et al*, 1967) must be regarded with reserve: the Norseman sequence (Bekker 1963) of 85,000 feet is exaggerated, for some evidence is now available of east facings in the Mt Thirsty Group at the top, and this group is not now believed to represent a continuation of the west facing Norseman Homocline. Taking into account the thickness estimated in Table 1 and a conservative estimate of the Norseman sequence, together with the known thickness of the Kurrawang Beds, a total thickness of not far short of 100,000 feet of igneous rocks and sediments is inferred, and about 40,000 feet in the succession within the Causeway Bed-Kurrawang Beds sequence. This assumes that the Norseman sequence does come in largely *below* the Causeway Beds.

Admittedly, no complete section can be measured across the strike, and the figures obtained are the result of a synthesis of various sections—and thus no more than an approximation. The effects of tectonic and depositional thinning and igneous lensing cannot be assessed, though tectonic thinning will tend to reduce the original thickness. Yet it appears that at least down to the stratigraphic level of the base of the Causeway Beds, and very probably right down into the Norseman sequence to the lowest unit of all, the Penneshaw Beds, we are dealing with a single thick geosynclinal infilling, without *major* discontinuity, a sequence that, in spite of its thickness, may be reasonably regarded as one system. Horwitz and Sofoulis (1965) have suggested that there is a major unconformity between the upper and lower parts of this very thick sequence, but on the basis of limited evidence. Mapping recently carried out by the writer south of Widgiemooltha has indicated that the Causeway Beds extend southwards through the unnamed lake east of Dordie Rocks, and if there is any major unconformity it must be between there and the Norseman sequence beyond the northern Causeway, to the south of Hayes Hill.

The Acid Rocks. No rocks which have been unequivocally identified as acid volcanics have been recognised within the area studied. O'Beirne (1968) has stressed the difficulty in differentiating between surface volcanics and high level intrusions amongst the acid rocks loosely termed "porphyries" by local geologists. Reasonably detailed field and microscopic studies of the "porphyries" in this area have suggested that they are of two kinds—sheared acid porphyries of igneous origin and *porphyroids*, rocks which have the porcellainous appearance and same colour characteristics as the sheared igneous intrusions, but, though they may or may not display inset, larger crystals of albite or oligoclase, also display "ghost" relics of conglomerate pebbles. The pebbles are mostly extensively homogenised, but, in rare cases they are sufficiently unaltered to reveal the polymictic character of the conglomerate, from which they have apparently been derived by a form of metasomatism. Some porphyroids display ghost stratification, particularly near to the outer margin of the body, and the microtextures of the matrix of the porphyroid conglomerates commonly retain features indicating derivation from greywacke material, by a process of shearing, limited metasomatism and homogenisation. A limited number of chemical analyses of these porphyroid rocks by O'Beirne (1968) reveals variation patterns among the major elements that are unlike those of the "porphyries" of igneous origin: in general, it may be said that the variations are more marked and irregular, reflecting, apparently, compositional variations across the stratification of the original sediments. It must, however, be stressed that further geochemical studies are called for, especially in the form of very detailed studies of individual porphyroid occurrences. The porphyroid metasomatism certainly involves soda enrichment and O'Beirne suggests that it may, perhaps, best be regarded as a localised "metamorphic metasomatism" rather than a regional scale process. Some evidence of grouping of porphyroid occurrences close to granite occurrences, as at Widgiemooltha, does suggest the possibility that the process may be an outlying contact metasomatism related to the process of granite emplacement. The alternative is that it is a low grade metasomatism, mainly affecting rudites, and accompanying shearing and metamorphism, but not directly related to granite emplacement, in time and space. The porphyroids present a problem because, while it is quite easy to distinguish them from metamorphosed igneous porphyries in good lake shore outcrops, in poor inland outcrops they are quite indistinguishable from them.

No lava flow structures at all have been detected in the acid rocks, no vesicular structure and no occurrences of agglomerates or tuffs. The very thickness of some of the individual units seems to preclude surface volcanic origin, in some cases being in excess of half a mile without any variation in the nature of the rock exposed. It has been a local practice to refer to metagreywackes crammed with angular felspars as *crystal tuffs*, but the writer does not follow this usage—while it is, admittedly, difficult to account for such felspar-crammed wackes, we know far too little about the bare, vegetationless land surfaces of this ancient time, of the physical conditions pertaining to it (which possibly involved a reducing, anoxygenic atmosphere) and the processes of weathering and sedimentation thereon, to exclude derivation of such felspar detritus from other than volcanic sources.

The Ophiolites. The ophiolite belts are concordant and complex in internal structure, changing their character very rapidly along the strike, both as regards their total width and their internal stratigraphy: the internal sills seem to be impersistent along the strike and there is some evidence of shallow, lensoid (funnel-shaped) form at Yilmia: and the degree of shearing and metamorphism is also variable along the strike. It is certain that much of the thinning of the belts (e.g. the Yilmia Main Ophiolite Belt which thins from two miles width to negligible width in about two miles strike distance) is due to shearing but this shearing may be located on the primary constrictions in the ophiolite belts. It seems quite certain that, considering the relationships between the pillowed and unpillowed, basic and ultrabasic metavolcanics on the one hand, and the coarsely crystallised rocks of the sill-form intrusions within the ophiolite belts on the other, a division into *older* and *younger* greenstones is unrealistic. The volcanics were characteristically erupted during periods of deposition of predominantly pelitic material, now represented by dark, fine, commonly carbonaceous metapelites, and one may reasonably attribute this association to eruption during a period of deepening of the basin of deposition. The sills are taken to represent penecontemporaneous eruptions of magma from the same stem, impeded on its passage to the surface by the damming effect of the early sea floor volcanic effusions, and so spread out laterally to fill favourable partings. There are rare, unmetamorphosed relics of felspyroxenites, norites, gabbros and dolerites. Their differentiation pattern, in the case of the best preserved examples—two sills in the Main Yilmia Ophiolite belt—is not unlike that of the Stillwater Intrusion, Montana (Hess, 1960). They are rare, unmetamorphosed relics of felspathic bronzitite cumulate. The serpentinites seem to represent something quite apart from the fine tremolite-chlorite ultrabasic rocks which commonly enclose them and seem, from chemical evidence, to have been picrite-basalts, though now converted to virtually felspar-free tremolite-actinolite/chlorite aggregates. Rather do the serpentinites appear to be metamorphosed ultrabasic intrusions, stemming from the same parental magma as the rocks of the differentiated sills. However, many of the serpentinites have the form of discrete ultrabasic bodies (of sill form ?) and are not simply the lower layers of gravity differentiated sills. There appear to be two distinct types of serpentinite occurrence:—

(a) *Discrete sills* (and cross-cutting intrusions?) This is the type represented at Yilmia and on the Lefroy Peninsula. It is believed to be the most favourable type of body for nickeliferous sulphide concentrations (mostly at the lower contact). They consist of serpentinite with marginal amphibolitic and chloritic rocks, but no associated gabbroic phases.

(b) *Lower layers of gravity differentiated sills*. While the peridotite basal phase layer of the Yilmia Sills is only slightly serpentinised, and there appears to be no representative of this type of serpentinite occurrences in this area, evidence from Ora Banda (Williams, 1967) and the Norseman Mission Sill (McCall, unpublished results) suggests that a substantial serpentinite body can be formed in the basal layers of a complex layered sill. Evidence from the Jimberlana Norite Intrusion at Mt. Norcott (Campbell, McCall and Tyrwhitt, unpublished manuscript, "The Jimberlana Norite, Western Australia—a smaller analogue of the Great Dyke of Rhodesia") shows that the serpentinisation is initially quite independent of regional metamorphism. Indications are that such serpentinite bodies show striking green staining by nickel, but are not such promising prospects for sulphide mineralisation as the discrete ultrabasic bodies.

The most difficult problem is the manner of separation of the ultrabasic melt that forms the discrete bodies of type (a) from the stem magma —presumably basaltic. It is noteworthy in respect of this unsolved problem that the Jimberlana Intrusion (Campbell, 1966: Campbell, McCall & Tyrwhitt, *op. cit.*), a large layered dyke-like body, reveals peridotite and picrite masses in the Ul layer (felspathic pyroxenite), and these appear to have formed small, discrete magmatic injections into the pyroxenite, with which they are unquestionably co-magmatic. It seems very unlikely that the discrete serpentinites represent injections of a primary ultrabasic magma, and are not derived from the common basaltic stem.

The sills of type (a) seem to be intruded slightly earlier than the layered sills, marking a slightly earlier phase in the penecontemporaneous sill emplacement process in each ophiolite belt (evidence from Yilmia). The associated tremolite-chlorite ultrabasics enveloping such discrete sills have the composition of picrites, but their origin remains obscure. Some fine-textured amphibolitic ultrabasics could prove to be regional metamorphic aureole derivatives of the serpentinites.

Chemical evidence and palimpsest textures leave no doubt that some type (a) serpentinites are derivatives of olivine-rich peridotites and dunites. Where intensely sheared they have been converted into dolomitic rocks, as near Bayley's Workings, but there is no reason to support, and every reason to discount, hypotheses of a genetic relationship to sedimentary dolomites.

Metabasite breccias have also been recognised, some on the Lefroy Peninsula being hyaloclastite breccias containing broken pillows. No other metabasite pyroclasts have been identified.

Metasediments. The metasediments are described in detail in accompanying papers dealing with the individual sub-areas. The only point that calls for comment here is the absence of banded iron formations and abundance in the lower part of the sequence of amphibolitic metasediments. In some of the Causeway Beds amphibole occurs as radiating prism clusters or "suns", and also as pods and discrete layers, which may show graded bedding, picked out by amphibole crystals. The origin of such amphibolitic metasediments has always been obscure.

Some metamorphic differentiation is suspected, for metasediments in the immediate vicinity of ophiolites tend to be amphibolitic. Yet this may be due rather to a concentration of material derived from the volcanics, though the fact that the amphibolite concentrations tend to occur at both upper and lower boundaries of the ophiolite belts favours the former explanation. Amphibolitic metasediments may also be due to chemical sedimentation, that is derived from metasediments with a significant CaMgFe content. Similarities between the textures and mineralogy of some of the metasediments in the Causeway Beds and amphibolitic metasediments in the Mt. Belches area (McCall and Dunbar, 1967) which are associated with quartz-magnetite-grunerite rocks, metamorphosed banded ironstones, suggest that much of the amphibolitic metasedimentary material is of primary sedimentary origin. Probably, metamorphic differentiation, chemical sedimentation, and the incorporation of volcanic detritus including basic tuff material, are all genetic factors in the widespread derivation of such metasediments. Whatever their origin, the amphibolitic metasediments are easily distinguished from the amphibolitic meta-igneous rocks.

Metamorphism. Metamorphism throughout the area studied has produced Upper Green Schist Facies Assemblages. There is much evidence of inhomogeneity and disequibrium, particularly in the basic rocks which show unmetamorphosed relics. The felspars in the metagreywackes may be albite or oligoclase, and the latter appears anomalous in the Green Schist Facies according to the definitions of Turner and Verhoogen (1960). Glikson (1968) has suggested that the rocks of this region sustained a low pressure, *Abukuma* type, metamorphism (Miyashiro, 1961). This suggestion seems reasonable in the light of the nature of the metabasalt assemblages which show a marked deficiency of epidote-chlorite associations, and also with the preservation of unmetamorphosed relics in the sills.

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